A Sample Of Helium Gas Has A Volume Of 1.00 L. What Is The Final Volume If Both The Pressure And Kelvin

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Understanding how gases behave under different conditions is fundamental in chemistry and physics. When dealing with gases like helium, changes in pressure and temperature can significantly alter their volume. This article explores the principles governing these changes, focusing on a specific scenario involving helium gas. Through detailed explanations and practical examples, you'll learn how to determine the final volume of helium when both the pressure and temperature are varied, applying the ideal gas law.

Introduction to Gas Laws and Helium Behavior

Helium is a noble gas known for its inert properties and low atomic mass. Its behavior under different conditions is well described by the ideal gas law, which relates pressure, volume, temperature, and amount of gas.

Key Concepts:

- Ideal Gas Law: PV = nRT
- Variables:
- P = pressure
- V = volume
- n = number of moles
- R = ideal gas constant
- T = temperature in Kelvin

Understanding how each variable interrelates allows us to predict how the volume of helium changes when others are altered.

Scenario Description: Initial and Final Conditions

Suppose you have a sample of helium gas with the following initial conditions:

- Initial Volume (V_1): 1.00 L
- Initial Pressure (P_1): 1.00 atm

- Initial Temperature (T_1): 300 K

Now, consider that both the pressure and temperature change to new values:

- Final Pressure (P_2): 2.00 atm
- Final Temperature (T_2): 600 K

The goal is to determine the final volume (V_2) of the helium gas after these changes occur.

Important Assumptions:

- The amount of helium (n) remains constant.
- The gas behaves ideally.
- No leaks or other external factors affect the gas.

Applying the Combined Gas Law

Since the quantity of gas and the gas's nature remain unchanged, the combined gas law provides a straightforward way to find the final volume:

Combined Gas Law Formula:

$$ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} $$

This formula links the initial and final states of the gas, incorporating pressure, volume, and temperature.

Step-by-Step Calculation:

1. Identify known values:

- $ P_1 = 1.00\, \text{atm} $
- $ V_1 = 1.00\, \text{L} $
- $ T_1 = 300\, \text{K} $
- $ P_2 = 2.00\, \text{atm} $
- $ T_2 = 600\, \text{K} $

2. Rearranged formula to solve for $ V_2 $:

$$ V_2 = V_1 \times \frac{P_1}{P_2} \times \frac{T_2}{T_1} $$

3. Plug in the values:

$$ V_2 = 1.00\, \text{L} \times \frac{1.00\, \text{atm}}{2.00\, \text{atm}} \times \frac{600\, \text{K}}{300\, \text{K}} $$

4. Perform calculations:

$$ V_2 = 1.00\, \text{L} \times 0.5 \times 2 $$

$$ V_2 = 1.00\, \text{L} $$

Result:

The final volume of the helium gas remains 1.00 L after the changes in pressure and temperature.

Understanding the Results and Implications

The calculation illustrates several important principles in gas behavior:

When Pressure Doubles and Temperature Doubles

- The increase in pressure tends to compress the gas, decreasing volume.
- The increase in temperature tends to expand the gas, increasing volume.
- These effects can offset each other, leading to no net change in volume, as observed in this scenario.

Real-World Applications

This understanding is crucial in various fields:

- Industrial Gas Storage: Ensuring safe and efficient storage under different conditions.
- Chemical Reactions: Predicting gas volume changes during reactions involving heating or pressurization.
- Environmental Science: Modeling how gases expand or compress in the atmosphere or under different environmental conditions.

Additional Considerations and Variations

While the ideal gas law provides a good approximation, real gases may deviate slightly due to interactions between molecules, especially at high pressures or low temperatures.

Factors Affecting Gas Behavior:

- Non-ideal behavior: Deviations become significant under extreme conditions.
- Molecular interactions: Attractive or repulsive forces affect volume and pressure.
- Gas purity: Impurities can alter the behavior.

Advanced Scenarios:

- If the amount of helium changes (e.g., adding or removing gas), the calculations would need to account for moles of gas.
- When dealing with gases other than helium, molecular weight and specific properties may influence calculations.

Conclusion

In summary, understanding how to calculate the final volume of a gas when pressure and temperature change involves applying the combined gas law. In the example provided, with both pressure and temperature doubling, the helium gas's volume remains constant at 1.00 L. This demonstrates the delicate balance between pressure and temperature effects on gas volume, highlighting the importance of gas laws in scientific and industrial applications. Mastery of these concepts enables scientists and engineers to predict and manipulate gas behavior effectively across various scenarios.

Summary of Key Points

- The ideal gas law and combined gas law are essential tools for understanding gas behavior.
- When both pressure and temperature change, their effects on volume can offset each other.
- Calculations involve substituting known initial and final conditions into the combined gas law formula.
- Real-world applications extend across industries, from manufacturing to environmental science.

By mastering these principles, you can confidently analyze and predict the behavior of gases like helium under various conditions, ensuring safety, efficiency, and scientific accuracy.

Frequently Asked Questions

What is the relationship between pressure and volume of helium gas at constant temperature?

At constant temperature, pressure and volume are inversely related, as described by Boyle's Law: $P_1V_1 = P_2V_2$.

If the pressure of helium gas doubles while temperature remains constant, what happens to its volume?

The volume halves because of Boyle's Law, so the final volume becomes 0.50 L.

How does increasing temperature affect the volume of helium gas if pressure remains constant?

Increasing temperature causes the volume to increase proportionally, according to Charles's Law.

Given a sample of helium gas at 1.00 L volume and a certain pressure and temperature, how do you find the final volume if both pressure and temperature change?

Use the combined gas law: $(P_1V_1)/T_1 = (P_2V_2)/T_2$, then solve for V_2.

What is the combined gas law formula used to calculate the final volume of helium gas when both pressure and temperature change?

$V_2 = (P_1V_1T_2) / (P_2T_1)$.

If the initial pressure is 1 atm, temperature is 300 K, and the final pressure is 2 atm with temperature at 600 K, what is the final volume of the helium gas?

$V_2 = (1 \text{ atm} \times 1.00 \text{ L} \times 600 \text{ K}) / (2 \text{ atm} \times 300 \text{ K}) = (600) / (600) = 1.00 \text{ L}$.

Why is Kelvin temperature used in gas law calculations instead of Celsius?

Kelvin is used because gas laws are based on absolute temperature, which directly relates to particle kinetic energy and ensures calculations are physically meaningful.

Can the volume of helium gas change if both pressure and temperature are kept constant?

No, if both pressure and temperature remain constant, the volume remains unchanged according to Boyle's and Charles's laws.

Additional Resources

Helium Gas Volume Change Under Varying Pressure and Temperature Conditions: An In-Depth Analysis

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Introduction: The Significance of Gas Behavior in Scientific and Practical Contexts

Understanding the behavior of gases under different conditions is fundamental to various scientific disciplines, including chemistry, physics, and engineering. Helium, a noble gas known for its inertness and unique physical properties, serves as a critical subject in gas law studies. Its applications range from scientific research to medical imaging and even aerospace engineering. The question at hand — "A sample of helium gas has a volume of 1.00 L. What is the final volume if both the pressure and temperature are changed?" — exemplifies core principles of gas behavior, specifically how pressure and temperature influence volume, as described by the ideal gas law.

This article aims to explore the scientific principles underpinning gas behavior, analyze the specific case of helium gas volume change, and provide detailed calculations and explanations to elucidate the process. By doing so, we will delve into the concepts of Boyle's Law and Charles's Law, the combined gas law, and the assumptions involved when applying these laws to real-world situations.

Understanding the Fundamentals: Gas Laws and Their Interplay

1. The Ideal Gas Law: Foundation of Gas Behavior

The ideal gas law is a fundamental equation that relates pressure (P), volume (V), temperature (T), and the amount of gas (n) in moles:

$$ PV = nRT $$

Where:
- P = pressure (atm or Pa)
- V = volume (L or m^3)
- n = number of moles

- R = universal gas constant ($0.082057 \, \text{L·atm/(mol·K)}$)
- T = temperature in Kelvin (K)

This law assumes ideal behavior, meaning the gas particles do not interact and occupy negligible volume. While real gases deviate slightly, helium’s inertness and small atomic size make it closely approximate ideal behavior under many conditions.

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2. Boyle’s Law: Pressure and Volume Relationship at Constant Temperature

Boyle's Law states that, at constant temperature and amount of gas, the pressure and volume of a gas are inversely proportional:

$$P_1 V_1 = P_2 V_2$$

This means if the pressure increases, the volume decreases proportionally, provided temperature remains unchanged.

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3. Charles’s Law: Temperature and Volume Relationship at Constant Pressure

Charles's Law indicates that, at constant pressure and amount of gas, the volume of a gas is directly proportional to its temperature in Kelvin:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

An increase in temperature results in an increase in volume, assuming pressure remains constant.

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4. The Combined Gas Law: Integrating Boyle’s and Charles’s Laws

When both pressure and temperature change simultaneously, the combined gas law is employed:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

This equation enables the calculation of the final volume (V_2) of a gas after changes in pressure (P) and temperature (T), provided initial conditions are known.

Application to Helium Gas: Setting Up the Problem

Let's formalize the problem:

- Initial volume, $V_1 = 1.00\, \text{L}$
- Initial pressure, P_1 (assumed to be standard atmospheric pressure, unless specified)
- Initial temperature, T_1 in Kelvin
- Final pressure, P_2
- Final temperature, T_2 in Kelvin
- Final volume, V_2 (unknown)

Since the problem states that both the pressure and Kelvin temperature are changing, but does not specify their initial or final values, for the purpose of comprehensive analysis, we'll explore several scenarios with typical conditions, and demonstrate the calculation process.

Assumptions and Typical Conditions

In most standard problems, initial conditions are taken as:

- $P_1 = 1\, \text{atm}$ (at sea level)
- $T_1 = 273.15\, \text{K}$ (freezing point of water, standard temperature)
- $V_1 = 1.00\, \text{L}$

Suppose the final conditions are:

- P_2 = 0.5 atm (pressure decreased)
- T_2 = 546.30 K (temperature doubled)

These are illustrative figures; actual values depend on problem specifics.

Step-by-Step Calculation of Final Volume

Using the combined gas law:

$$ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} $$

Rearranged to solve for V_2:

$$ V_2 = V_1 \times \frac{P_1}{P_2} \times \frac{T_2}{T_1} $$

Plugging in the assumed values:

$$ V_2 = 1.00\, \text{L} \times \frac{1\, \text{atm}}{0.5\, \text{atm}} \times \frac{546.30\, \text{K}}{273.15\, \text{K}} $$

Calculations:

- $\frac{1}{0.5} = 2$
- $\frac{546.30}{273.15} = 2$

Therefore:

$$ V_2 = 1.00\, \text{L} \times 2 \times 2 = 4.00\, \text{L} $$

Result: The final volume of helium under these specific conditions would be approximately 4.00 liters.

Analyzing the Results: Insights and Implications

This calculation reveals several key insights:

a. The Effect of Pressure Reduction
Lowering the pressure from 1 atm to 0.5 atm effectively doubles the volume, assuming constant temperature, as per Boyle's Law.

b. The Effect of Temperature Increase
Doubling the Kelvin temperature doubles the volume, per Charles’s Law, when pressure is held constant. In the combined scenario, both effects compound, leading to a quadrupling of the volume.

c. Real-World Applications
Understanding these relationships is crucial in applications like helium balloon inflation, gas storage, and in scientific experiments where precise control of gas conditions is essential.

Complexities and Limitations in Real-World Scenarios

While the ideal gas law provides a solid foundation, real gases like helium exhibit deviations under certain conditions:

- High Pressure or Low Temperature: Gases may deviate from ideal behavior due to intermolecular forces and volume occupied by particles.
- Non-Ideal Behavior Corrections: Van der Waals equation introduces correction factors for pressure and volume, improving accuracy.

In most laboratory conditions, helium’s behavior remains close to ideal, making the ideal gas law a reliable approximation. However, engineers and scientists must be cautious when operating near extreme conditions.

Conclusion: The Interplay of Pressure and Temperature in Gas Volume Dynamics

The relationship between pressure, temperature, and volume of gases is a cornerstone of physical chemistry, with practical significance across numerous scientific and industrial fields. The case of helium gas exemplifies how these variables interplay, with the combined gas law providing a straightforward method to predict volume changes under varying conditions.

By understanding the underlying principles, assumptions, and limitations of these laws, scientists can accurately model and manipulate gases for diverse applications. Whether in designing safer pressurized systems, optimizing helium use in medical or scientific contexts, or simply enhancing our comprehension of physical laws, mastery of these concepts remains essential.

In conclusion, the final volume of helium gas after simultaneous changes in pressure and Kelvin temperature depends directly on the ratios of initial and final conditions, as demonstrated through detailed calculations. Such analyses underpin the precise control and utilization of gases in both everyday and advanced technological contexts.

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Author's Note:
This comprehensive exploration emphasizes the importance of understanding fundamental gas laws and their application to real-world problems. Whether encountering similar questions in academics, industry, or research, a solid grasp of these principles enables accurate predictions and effective decision-making.

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